Introduction to geoinformation science

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Abstract

Here, we define a geoinformation system (GIS) as a system, which is designed to capture, store, manipulate, analyze, manage, and present geospatial data. In university education, we study geoinformation science that is the science underlying geographic concepts, applications, and systems. Geoinformation science is dedicated to advancing our understanding of geographic processes and spatial relationships through improved theory, methods, technology, and data. Since early days of GIS, use of geospatial data and analyses have drastically changed with increased pace during the last 20 years. Geospatial data and analyses are omnipresent in our information societies and there is an increasing need to understand the role and use of expanding geospatial data in our societies. Drivers of the development include enhanced global navigation satellite systems, miniaturization of sensors, three-dimensional remote sensing, open data, and software policies. Although the development in the use of geospatial data and analyses has been rapid, still most of the core concepts, principles, theories, methods, and algorithms of geoinformation science are not out-dated, merely those are applied with geospatial data of improved quality and larger coverage.

1. Definitions of geoinformatics

We will begin with the common definitions for "GIS" in order to understand each other. "GIS" may refer to geoinformatics, geographic information system, geoinformation system, or geoinformation science. There are some differences between these terms. Geoinformatics has been described as "the science and technology dealing with the structure and character of spatial information, its capture, its classification and qualification, its storage, processing, portrayal and dissemination, including the infrastructure necessary to secure optimal use of this information" or "the art, science or technology dealing with the acquisition, storage, processing production, presentation and dissemination of geoinformation" [1]. Then, a geoinformation system (GIS) is defined as a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data. GIS applications are tools that allow users to create interactive queries (user-created searches), analyze spatial information, edit data in maps, and present the results of all these operations [2]. Here, GIS is used as an abbreviation for geographic information system. In university education, GIS is applied whereas geoinformation science is studied and considered as the fundamental science integrating geographic concepts, applications, and systems. Geoinformation science is dedicated to advancing our understanding of geographic processes and spatial relationships through improved theory, methods, technology, and data. The last commonly used "GIS"-term is geomatics. It is a similarly used term which encompasses geoinformatics, but geomatics focuses more so on surveying.

2. Geospatial data and analyses are omnipresent

When we are using data characterizing objects, events, or phenomena that have a location in the geographical space, we are using geospatial data. Term "spatiotemporal data", on the other hand, is used if data are related to both space and time. Thus, both geospatial and spatiotemporal data contain some sort of geographic information, such as coordinates, an address, or city zip code. All human activities, including learning and decision making, take place in space and time [3] and, thus, there is an increasing need to understand the role and use of increasing geospatial data in our societies. Geospatial data is also supporting many business activities. It has been estimated that geospatial data supported decision making in business with a value of over 1 trillion US$ in 2016 [4]. The future looks promising for graduates with GIS skills and understanding: Linturi and Kuusi [5], for example, foresight that abundant professions include GIS experts in the near future. However, it should be noted that future professions can also include virtual decorator, e-sports coach, e-athlete, and our favorite - real virtual reality (VR) star [5].

Looking back at the history of geoinformation science, one of the first applications of spatial analysis is from epidemiology from 1832 [2]. Back then, the French geographer Charles Picquet represented the 48 districts of the city of Paris by halftone color gradient according to the number of deaths by cholera per 1,000 inhabitants. In 1854, John Snow determined the source of the cholera outbreak in London by marking points on a map depicting where the cholera victims lived, and connecting the cluster that he found with a nearby water source (Figure 1). This is seen as one of the earliest successful use-cases of spatial analyses. Although the basic elements of topography and theme existed already in cartography, the map by John Snow was unique as it used cartographic methods not only to depict but also to analyze clusters of geographically dependent phenomena [2].

Figure 1. E. W. Gilbert's version (1958) of the map by John Snow of the Soho cholera outbreak showing the clusters of cholera cases in the London epidemic of 1854 (Source: [2]).

The world's first proper operational GIS was developed in 1960 in Ottawa, Ontario, Canada, by the federal Department of Forestry and Rural Development. GIS was developed by Dr. Roger Tomlinson, and it was called the Canada Geographic Information System (CGIS) and was used to store, analyze, and manipulate data collected for the Canada Land Inventory [6]. Canada Land Inventory required information on soils, agriculture, recreation, wildlife, waterflow, forestry, and land use at a scale of 1:50,000. So, already in the first GIS, the information related to use of forest resources was analyzed. The CGIS was an improvement over previous applications of "computer mapping" as it provided capabilities for spatial overlay, measurement, and digitizing/scanning. The CGIS supported a Canada-wide national coordinate system that spanned the continent, coded lines as arcs having a true embedded topology and it stored the attribute and locational information in separate files. As a result of this, Dr. Tomlinson has become known as the "father of GIS", particularly for his use of overlays in promoting the spatial analysis of convergent geospatial data. The CGIS continued until the 1990s and supported federal and provincial resource planning and management. One of its strengths during those times was continent-wide analysis of complex datasets [6].

Since early days of GIS, use of geospatial data and analyses has changed drastically with increased pace during the last two decades. When research on geoinformation sciences commenced during the early 2000, there was practically no experience how to use global satellite navigation systems (GNSSs), navigators were essentially non-existing, daily location-based services or reporting of sport activities using online map services providing very high resolution satellite and aerial imagery were unheard of. Without a hesitation, development of the GNSS technology has been one of the driving forces behind the expansion of usage and application of spatial data and analyses. Until May 2, 2000 GNSS sensors had a thing called "selective availability" enabled meaning that an error of 50 m and of 100 m horizontally and vertically, respectively was added to the GNSS signals. Once it was disabled civilian users were allowed to receive a non-degraded signal globally [7] which improved the accuracy of user-grade GNSS devices considerably. The GNSS sensors have also successfully miniaturized since their early days. Nowadays, there is no need to carry a GNSS-device in a backpack with a separate antenna in your hand. Today, when people bike to work, they may carry multiple different GNSS sensors - a smartphone, a bike computer, and a smartwatch all have their own GNSS sensors. Map services are used for transportation planning, locating services, as well as tracking and analysing sport activities, among many other things. Early 21st century, we were not familiar with the everyday use of aerial imagery or high resolution satellite imagery that are prevailing at the time of writing. Also the location-based services, such as Uber, Facebook (some elements in it, especially location-based advertisements), and Tinder seemed to be surreal back in the beginning of 2000s. Back then, availability of the GIS software was also limited and only licensed software was generally used. Nowadays geospatial data can be analysed using various software and platforms including many open source alternatives. The amount of geospatial data has increased exponentially and they are widely provided as open data. Many countries have websites for sharing geospatial data side-by-side with other data sources. It should also be noted that although data itself would not be geospatial by its strict definition, they most often have a spatial element and can be linked to some other geospatial data, or can, at least theoretically, have some geospatial link. This is because most of the experiences, things, and events that form the data, have a location in space and time. From a philosophical point of view, only things like *a priori* truths (e.g. mathematical truths) are not dependent on space and time.

Figure 2. Various sensors can be used to create a digital replica of a forest (i.e. digital twin [8]). Drivers of the development in geoinformation science have been enhanced by global navigation satellite systems, miniaturization of the sensors, three-dimensional remote sensing, open data, and software policies.

When we are talking about digitalization in our societies, it is driven by new technologies for creating geospatial data and use of novel methodologies to analyse it, examples in Figure 2. Development in GNSS technology has eased the collection of geospatial data whereas miniaturization of the sensors, network coverage, and rapid wireless data transfer have enabled creation of sensor networks. The trendy term for sensor networks and interrelated computing devices is the “Internet of Things (IoT)”.

Airborne laser scanning (ALS) started the three dimensional revolution in remote sensing in environmental viewpoint, followed by re-invention of the image-matching derived photogrammetric point clouds that can both be used to characterize terrain, vegetation but also urban areas with unprecedented level of detail [9,10]. Miniaturization of sensors and GNSS technology has enabled use of drones for small-scale environmental mapping and monitoring [11–13]. Geospatial data collected by these varying sensor technologies easily become geospatial big data and one of the current challenges is how to efficiently analyse geospatial big data and how to handle issues related to data quality when data from different sources are fused in analyses. Therefore, artificial intelligence and machine learning methodologies are more and more used for spatial data analyses. The level of detail that geospatial data sets have reached, enable realistic visualizations and creation of virtual realities [14]. There is also another trendy term, namely “digital twin” meaning digital replica of the real world object (Figure 2). For example, a digital twin of forest would mean that we have an accurate 3D model representing each tree with multiple attributes describing tree characteristics in space and time.

To end up with, although use of geospatial information has increased and become prevalent in our lives, still most of the core concepts, principles, theories, methods and algorithms of geoinformation science are perfectly valid and up-to-date. Although the quality and amount of the geospatial data have increased, improved computational capacity, including for example cloud computing, enables detailed large-scale spatial analyses. In geospatial analyses, points, polygons, lines, and rasters continue to be adopted. Furthermore, our analyses regarding the real world is still limited by how well these data types can be used to capture the real world and its phenomena. In that way, geoinformation science is rather simple and straightforward - as long as we fully understand what we can do with the data we have.

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References

1. Contributors to Wikimedia projects Geoinformatics - Wikipedia Available online: https://en.wikipedia.org/wiki/Geoinformatics (accessed on Mar 17, 2020).
2. Contributors to Wikimedia projects Geographic information system - Wikipedia Available online: https://en.wikipedia.org/wiki/Geographic_information_system (accessed on Mar 17, 2020).
3. Harvey, D. Between Space and Time: Reflections on the Geographical Imagination. *Annals of the Association of American Geographers* 1990, *80*, 418–434.
4. Alphabeta The economic impact of geospatial services. **2016**.
5. Linturi, R.; Kuusi, O. Societal transformation 2018–2037: 100 anticipated radical technologies. *Publication of the Committee for the Future* **2018**, 485.
6. Contributors to Wikimedia projects Canada Geographic Information System - Wikipedia Available online: https://en.wikipedia.org/wiki/Canada_Geographic_Information_System (accessed on Apr 7, 2020).
7. Contributors to Wikimedia projects Global Positioning System - Wikipedia Available online: https://en.wikipedia.org/wiki/Global_Positioning_System#Development (accessed on Mar 17, 2020).
8. Vastaranta, M.; Saarinen, N.; Yrttimaa, T.; Kankare, V.; Junttila, S. Monitoring Forests in Space and Time Using Close-Range Sensing.
9. White, J.; Wulder, M.; Vastaranta, M.; Coops, N.; Pitt, D.; Woods, M. The Utility of Image-Based Point Clouds for Forest Inventory: A Comparison with Airborne Laser Scanning. *Forests* 2013, *4*, 518–536.
10. White, J.C.; Coops, N.C.; Wulder, M.A.; Vastaranta, M.; Hilker, T.; Tompalski, P. Remote Sensing Technologies for Enhancing Forest Inventories: A Review. *Canadian Journal of Remote Sensing* 2016, *42*, 619–641.
11. Puliti, S.; Ørka, H.; Gobakken, T.; Næsset, E. Inventory of Small Forest Areas Using an Unmanned Aerial System. *Remote Sensing* 2015, *7*, 9632–9654.
12. Saarinen, N.; Vastaranta, M.; Näsi, R.; Rosnell, T.; Hakala, T.; Honkavaara, E.; Wulder, M.; Luoma, V.; Tommaselli, A.; Imai, N.; et al. Assessing Biodiversity in Boreal Forests with UAV-Based Photogrammetric Point Clouds and Hyperspectral Imaging. *Remote Sensing* 2018, *10*, 338.
13. Imangholiloo, M.; Saarinen, N.; Markelin, L.; Rosnell, T.; Näsi, R.; Hakala, T.; Honkavaara, E.; Holopainen, M.; Hyyppä, J.; Vastaranta, M. Characterizing Seedling Stands Using Leaf-Off and Leaf-On Photogrammetric Point Clouds and Hyperspectral Imagery Acquired from Unmanned Aerial Vehicle. *Forests* 2019, *10*, 415.
14. Virtanen, J.-P.; Hyyppä, H.; Kämäräinen, A.; Hollström, T.; Vastaranta, M.; Hyyppä, J. Intelligent Open Data 3D Maps in a Collaborative Virtual World. *ISPRS International Journal of Geo-Information*

2015, *4*, 837–857.